

Idaho National Engineering and Environmental Laboratory

A Versatile Matched-Index-of-Refractive (MIR) System for Flows in Porous Media

INEEL Physics Dept. Manager:

Richard N. Wright, 208-526-6127

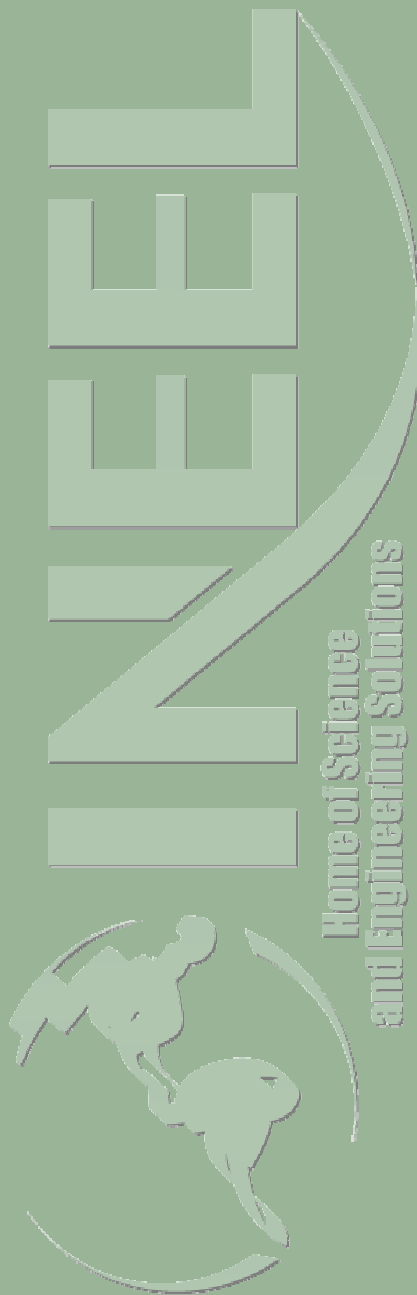
INEEL Technical Leader:

Donald M. McEligot, 208-526-2881

INEEL Program Manager:

Glenn E. McCreery, 208-526-5408

Idaho National Engineering and Environmental Laboratory (INEEL)
Idaho Falls, Idaho 83415-3885



Preliminary Summary

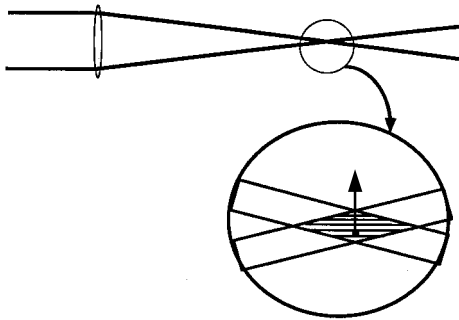
- *INEEL's large Matched-Index-of-Refraction (MIR) flow system is an excellent user facility which can be a valuable asset for research proposals*
- *Some past applications of refractive-index-matching techniques to optical flow measurements in porous media are mentioned later*
- *For further information, contact Prof. Don McEligot, INEEL/U. Arizona at (208)-526-2881 or dm6@inel.gov*

- *Experimental Thermal Science Advisory Committee recommended a central test facility for*
 - *Complex turbulent flows*
 - *Flows in porous media*
 - *Two-phase particulate flows**using refractive-index-matching techniques*
➔ *INEEL MIR flow system = World's largest*
- *Advantages*
 - *Versatile - internal/external flows, basic/applied research*
 - *Non-intrusive measurements*
 - *Good spatial and temporal resolution*
 - *Benchmark data*
- *Is an excellent user facility*

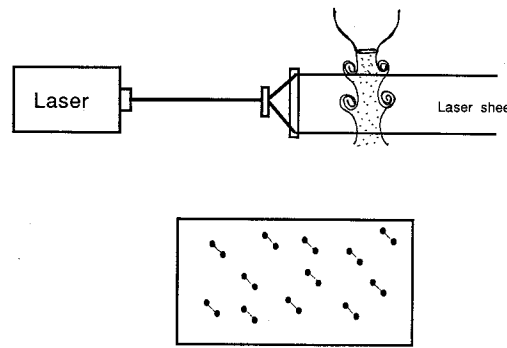
How does refractive-index-matching help?

- Optical techniques avoid disturbing the flow to be measured
- Typical approaches are LDV, PIV, PTV, flow visualization, PLIF, etc.

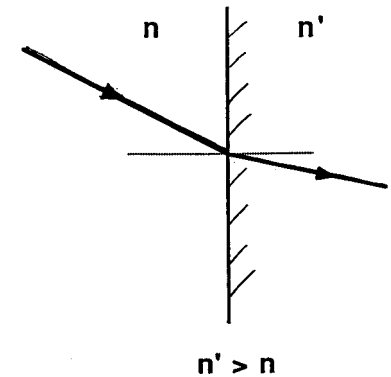
Laser Doppler Velocimetry



Particle Image Velocimetry

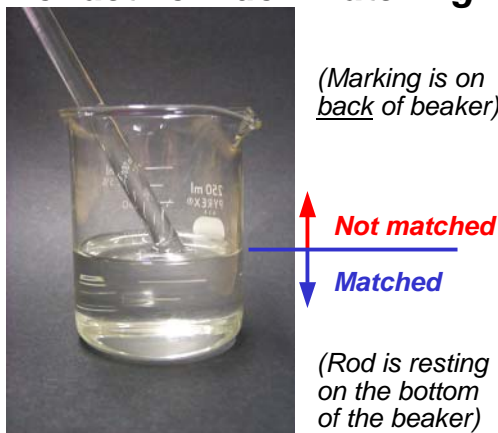


Snell's Law

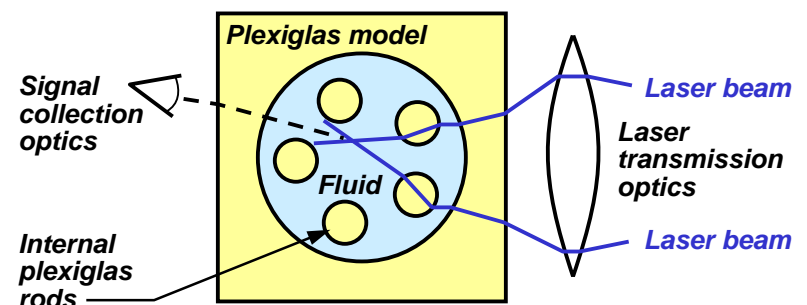


- Unless the refractive indices are matched, the view may be distorted or impossible even with "transparent" materials and position measurements may be incorrect

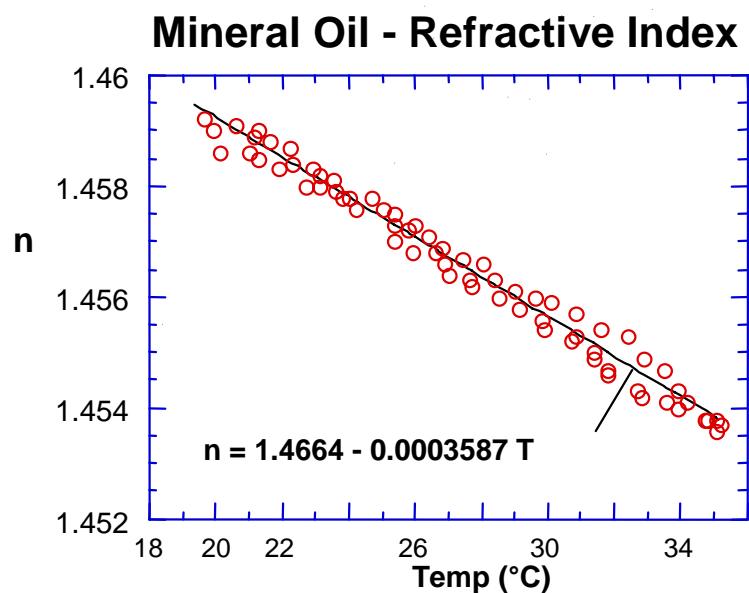
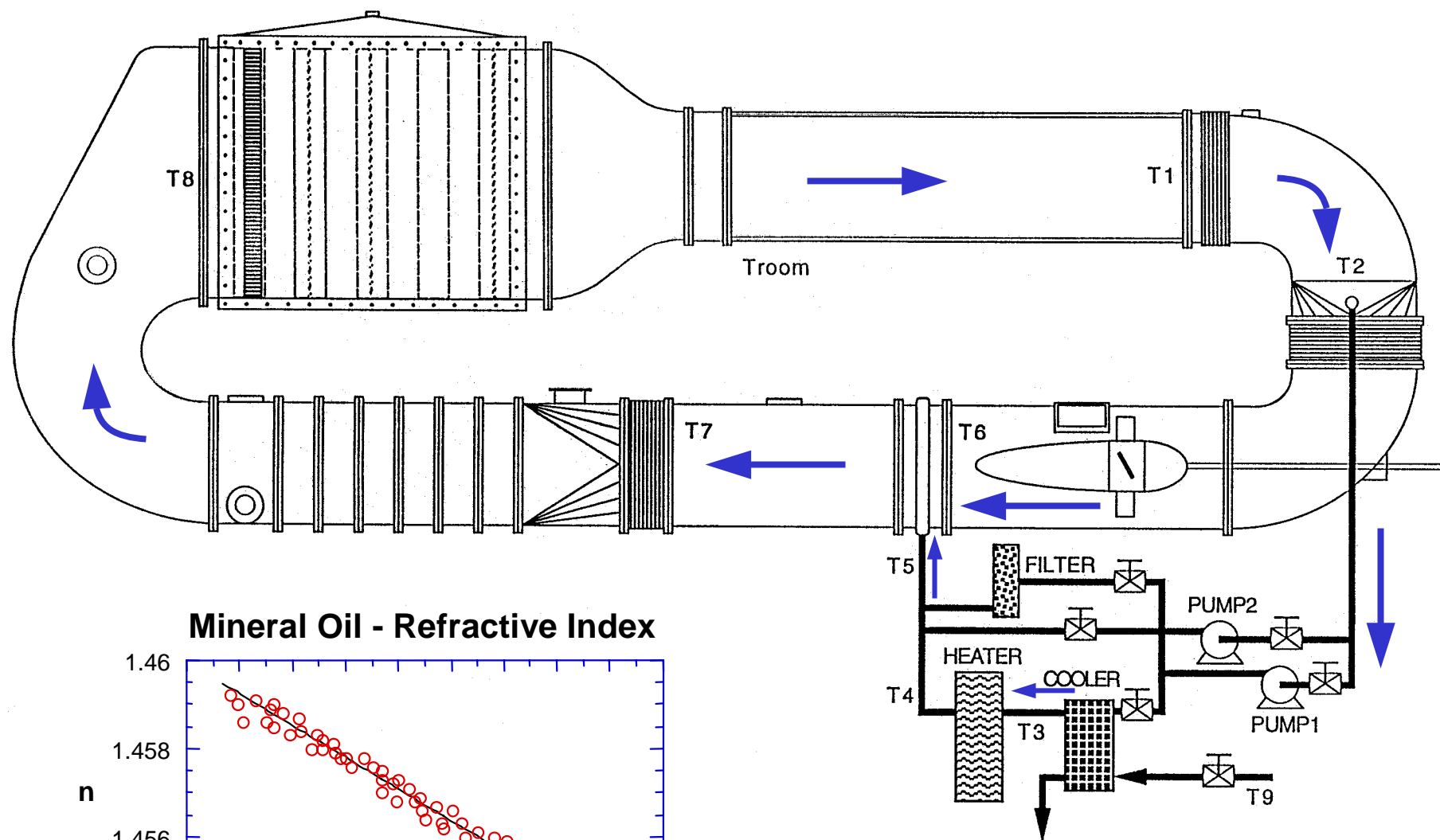
Example of application of refractive-index-matching



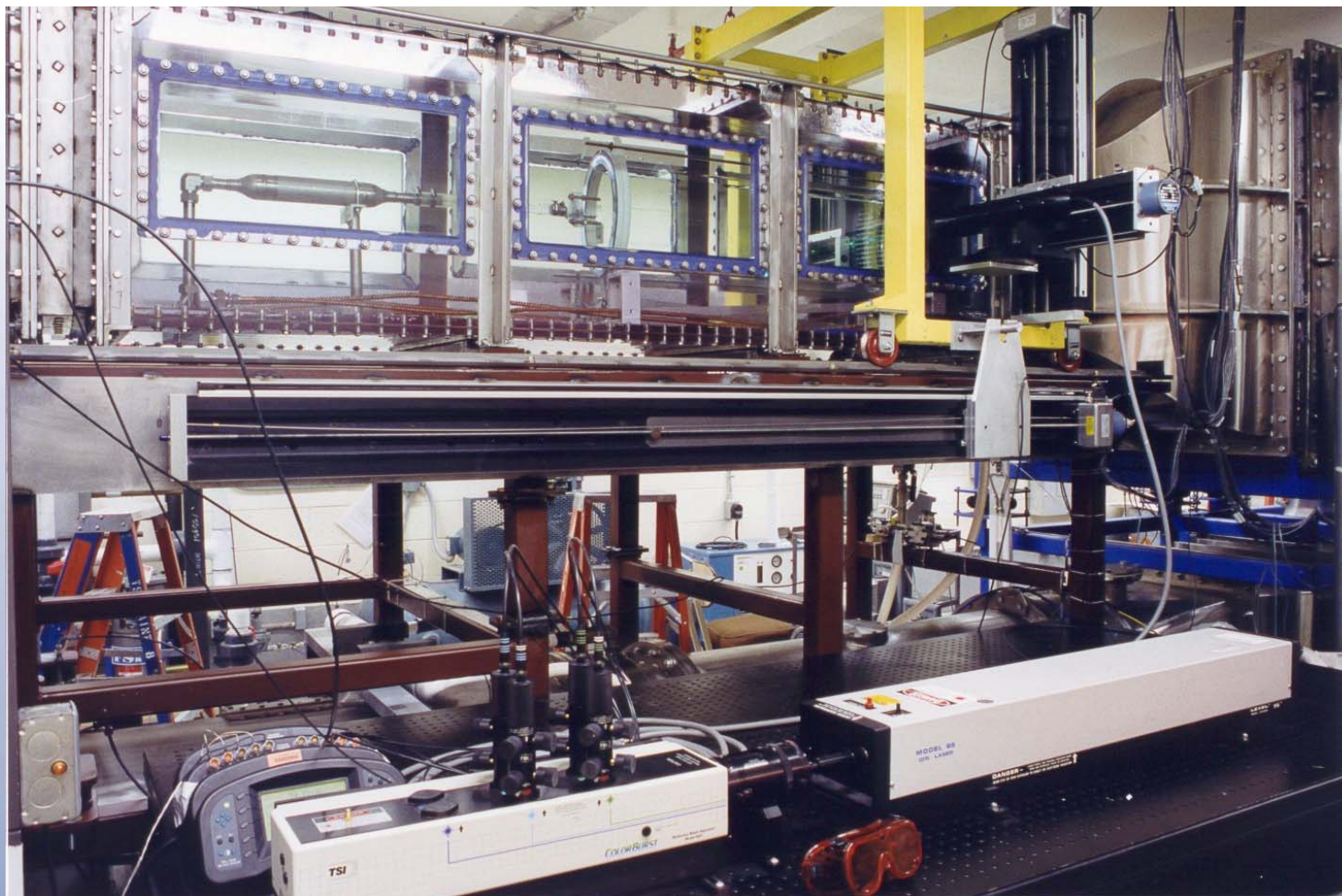
Refractive index not matched



The Large *INEEL* MIR Flow System



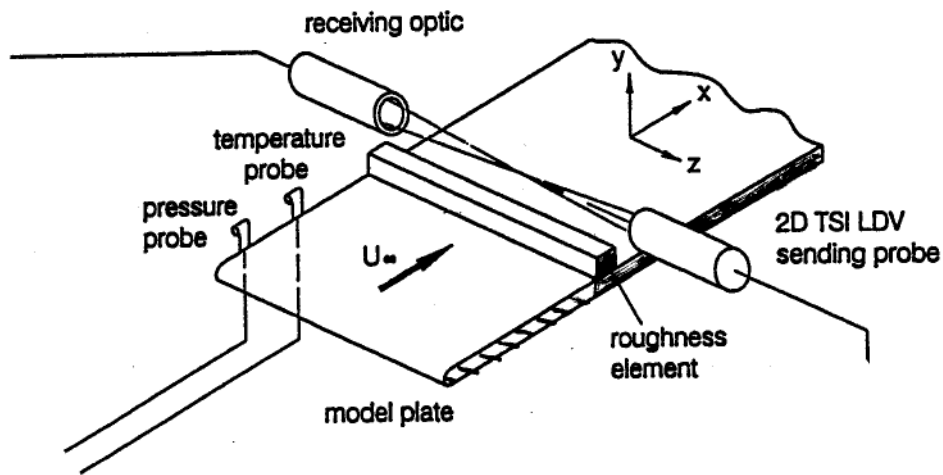
MIR Test Section



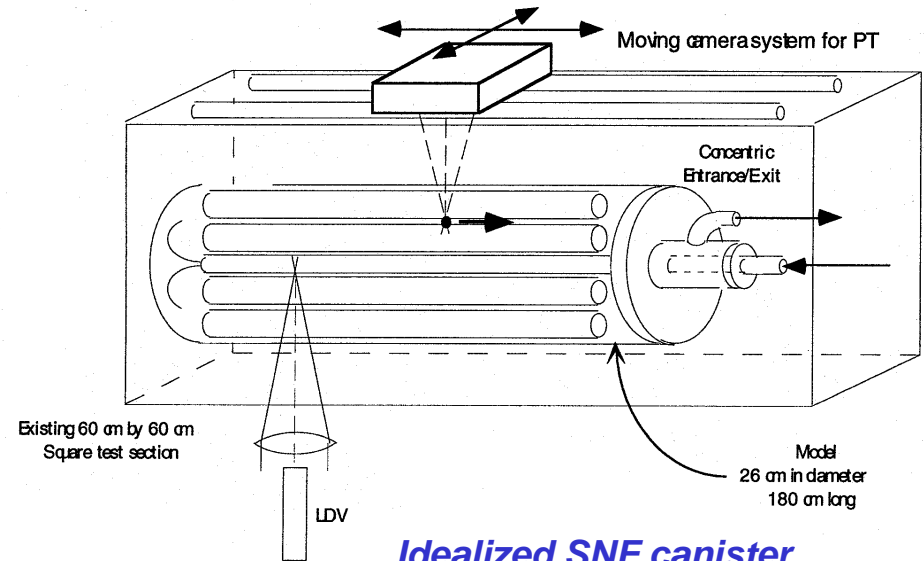
Advantages of INEEL MIR Flow System

- *Optical measuring techniques for internal and external geometries do not disturb the flow - LDV, PTV and MPT*
- *Refractive-index matching avoids optical distortion (and related problems)*
- *Can measure v and its products (uv) to $y = "0"$*
- *Low velocity $\rightarrow Re'' < 2 \times 10^5$ 1/m \rightarrow large size*
 - \rightarrow *Good spatial resolution*
- *Large size + low velocity $\rightarrow t^+ = tV/L \rightarrow t = t^+ L/V$*
 - \rightarrow *Good temporal resolution*
- *Refractive-index matching + forward scattering \rightarrow reduction of noise in near-wall data \rightarrow good signal-to-noise ratio*
 - \rightarrow *Benchmark data*

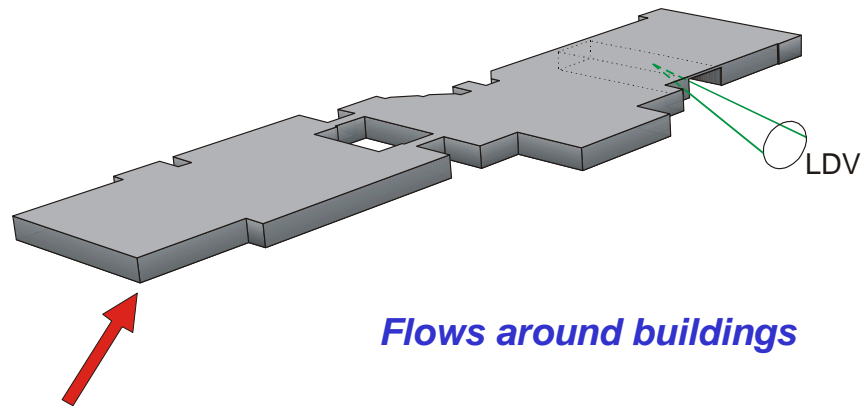
Recent and Current Experiments



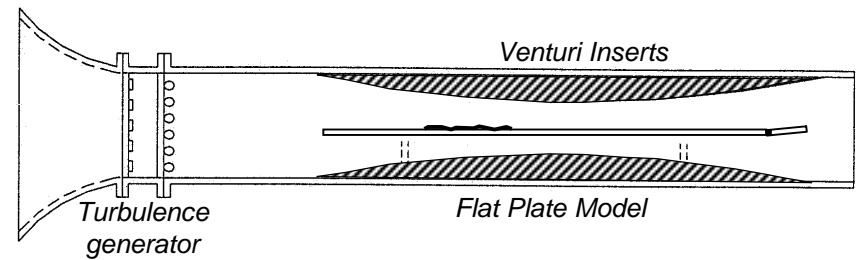
Boundary layer transition



Idealized SNF canister



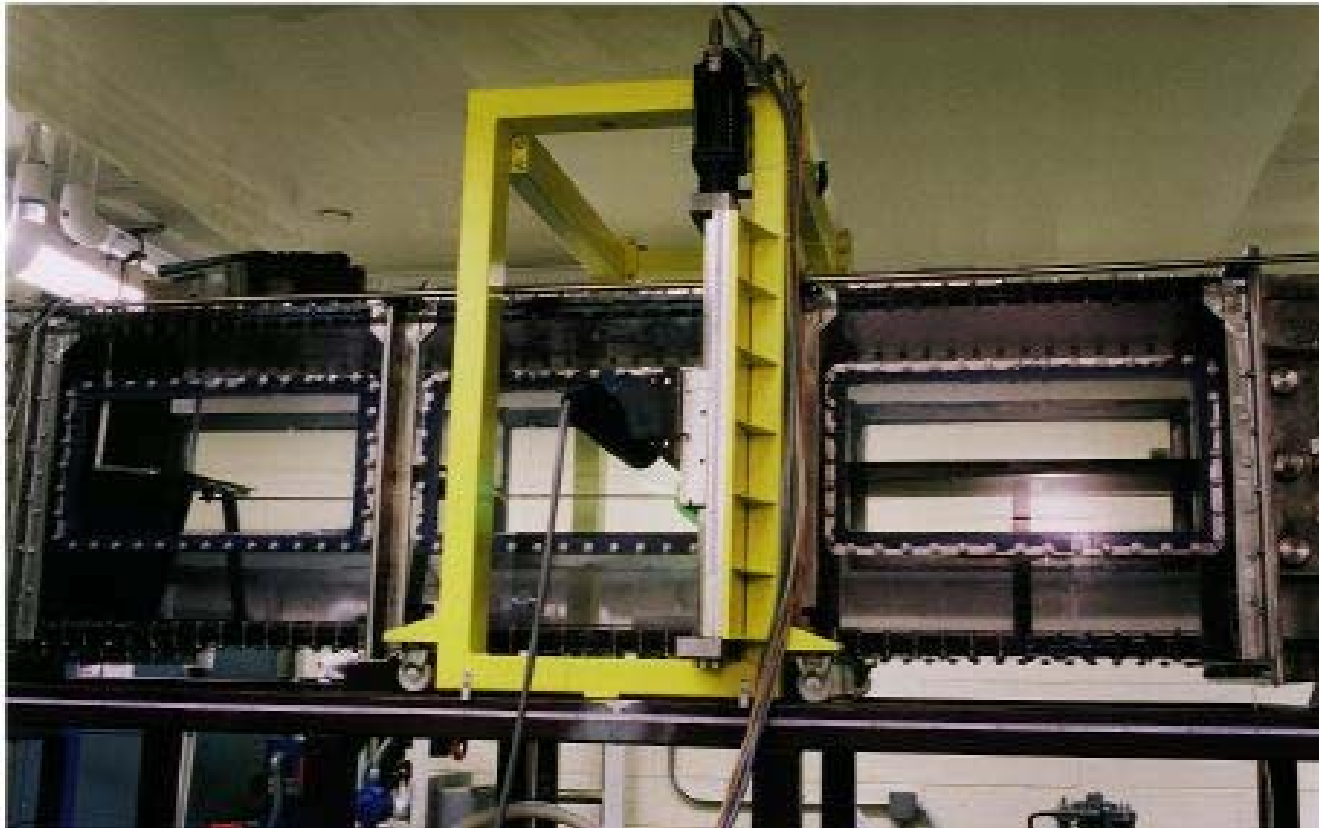
Flows around buildings



Realistic rough surfaces in turbomachinery

| <u>Project</u> | <u>Funding</u> | <u>Collaborators</u> | <u>Mission area</u> |
|---|-----------------------|-----------------------------|----------------------------|
| To date: | | | |
| Boundary layer transition | DFG, LDRD | Uni. Erlangen | Science, EE |
| EM Science SNF flows | DoE-EM | U. Idaho, OhSU | Science, EM |
| NERI complex flows | DoE-NEGA, | IowaSt, Japan, | Science, NE |
| | | UMaryland, UK | |
| Flows over buildings | CFRD | Bechtel SII | Nat. sec. |
| Rough blade surfaces | AFOSR | U. Idaho | Science, EE |
| Transient synthetic jets | AFOSR | U. Wyoming | Science |
| "Proposed" | | | |
| Nanofluidphysics | DoE-BES | NRL, Notre Dame | Science |
| Entropy generation in flows | DoE-BES | Duke, IIS Bangalore | Science, EE |
| μ-scale actuators | DoE, AFOSR | U. Wyoming | Science |
| Blade cooling | NASA | U. North Dakota | EE |

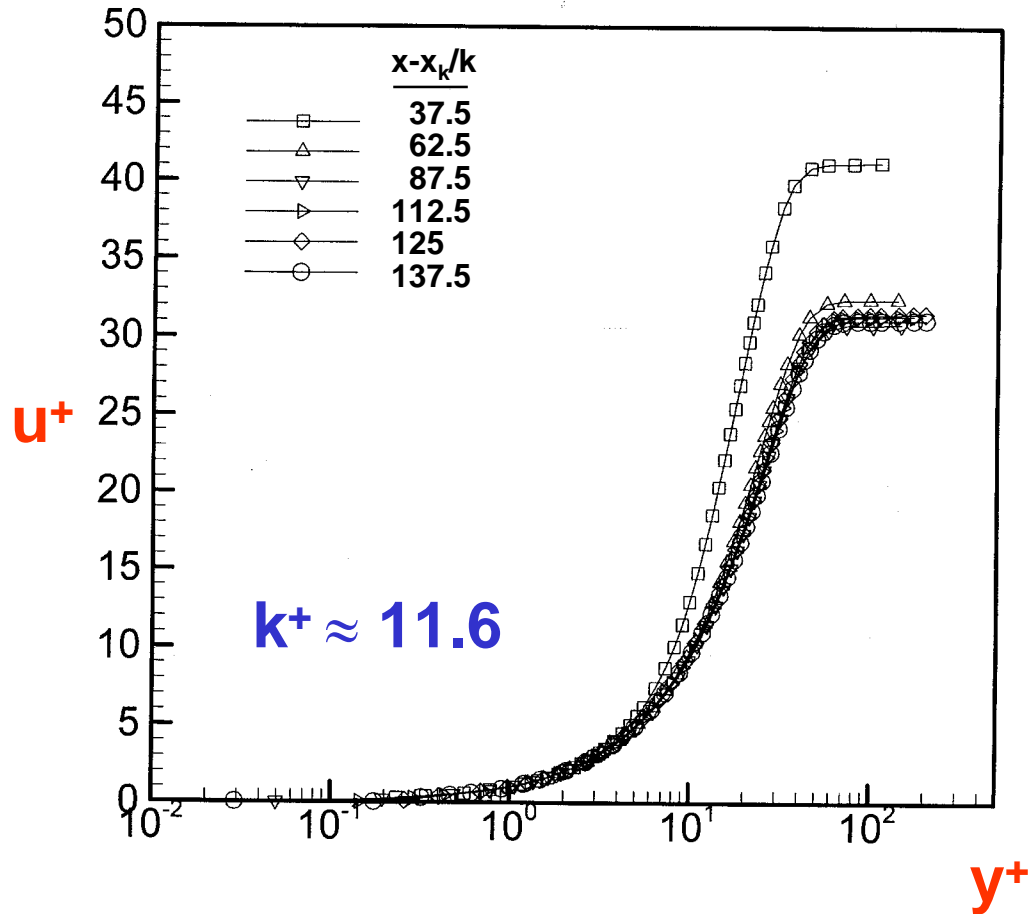
MIR Test Section with BLT Model Installed



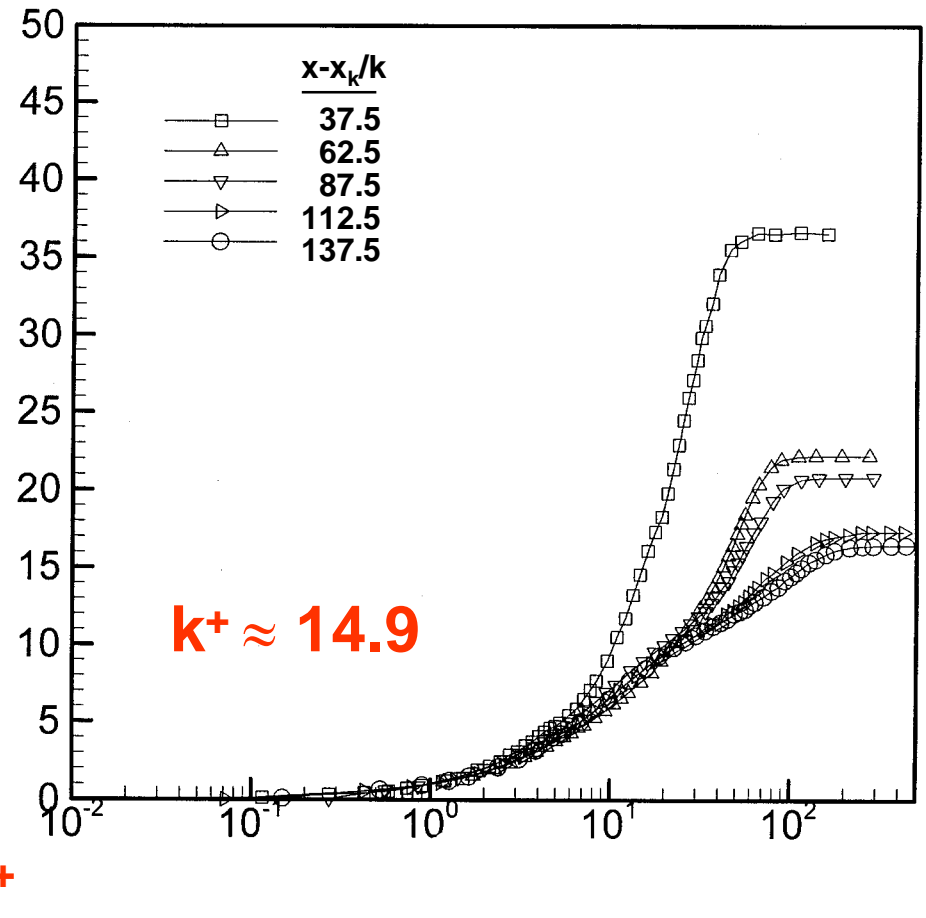
Flow is right to left

Mean velocity profiles, $u^+\{y^+\}$

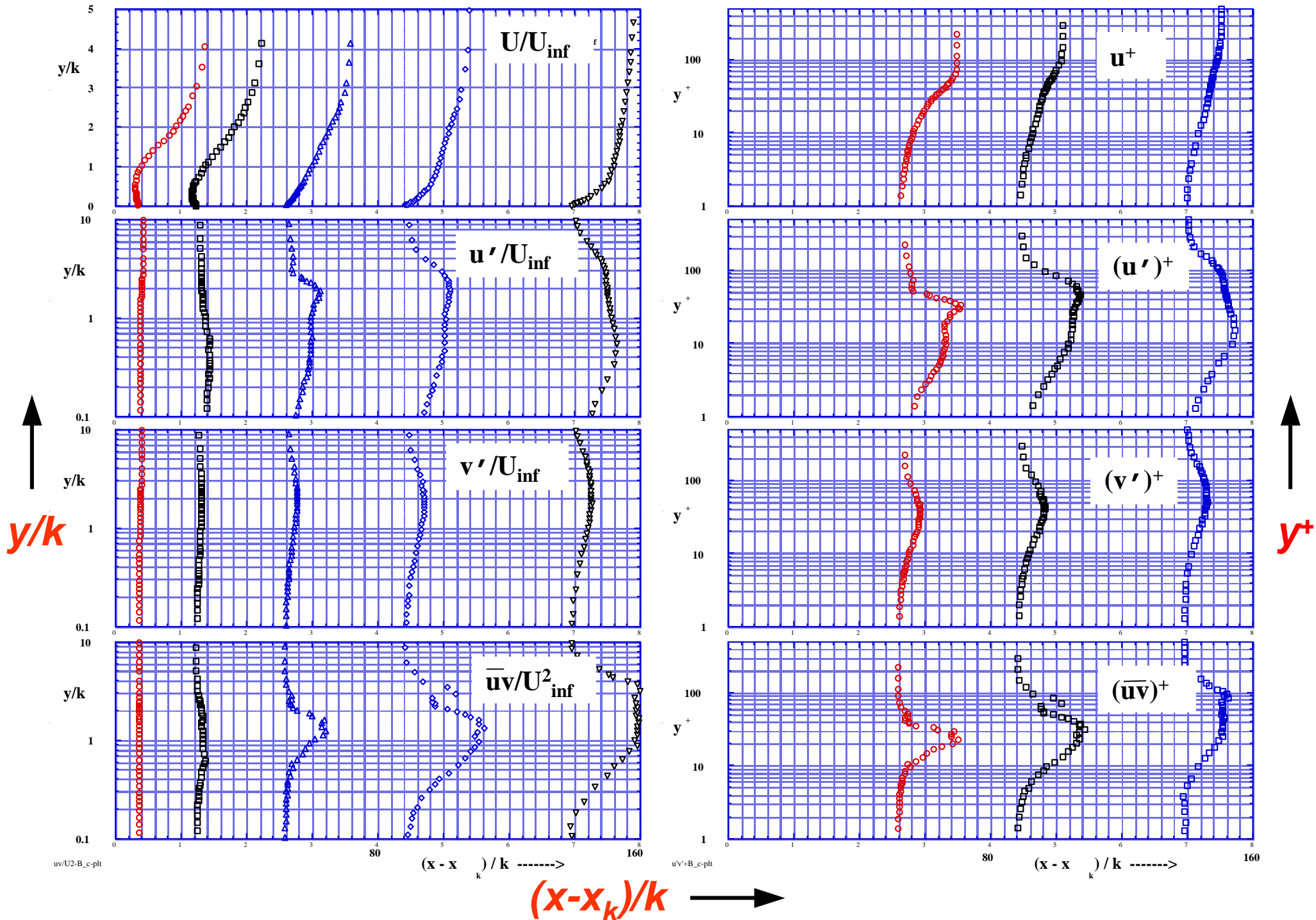
Laminar recovery



Transition to turbulent



Development of mean quantities downstream of 2-D rib ($k = 4 \text{ mm}$, $k^+ \approx 14.9$)



MIR Experiments for Porous Media

| | <u>Model</u> | <u>Measurements</u> |
|---|---|----------------------------|
| <i>Johnston, Dybbs & Edwards [1975]</i> | <i>Packed bed of spheres, sat</i> | <i>LDV</i> |
| <i>Edwards and Dybbs [1984]</i> | <i>Rod bundle, homogeneous, sat</i> <i>3-D rod matrix, homog, sat</i> | <i>LDV</i> <i>LDV</i> |
| <i>Yarlagadda and Yoganathan [1989]</i> | <i>Rod matrices, homog, sat</i> | <i>LDV</i> |
| <i>Saleh, Thovert & Adler [1993]</i> | <i>Foam, spheres, grains -</i> <i>partially-filled channel, homog, sat</i> | <i>PIV</i> |
| <i>Northrup et al. [1993]</i> | <i>Spheres, homog, saturated</i> | <i>Fluorescent PIV</i> |
| <i>Peurrung, Rashidi & Kulp [1995]</i> | <i>Spheres, homog, saturated</i> | <i>Fluorescent PTV</i> |
| <i>Cenedese and Viotti [1996]</i> | <i>Short rods, homog, saturated</i> | <i>PTV</i> |
| INEEL [1996] | Crossflow in rod bank | None |
| <i>Moroni and Cushman [2000]</i> | <i>Spheres, homog, saturated</i> | <i>PTV</i> |
| INEEL application | Fractures, sat (unsat?), transport | PTV, LDV? |

Potential Interactions

- Collaborative faculty projects in **INEEL** mission areas
- Faculty collaborative research proposals
- Faculty sabbatical leaves
- Doctoral dissertations
- Training students -- participation in ongoing experiments
- Training post doctoral associates
- Fluid mechanics conferences and workshops on topical areas
- Modification of facility to expand capabilities of interest
- Advisory committees

Potential Experiments for Subsurface Science

- *Transport in networks of fractured media*
- *Local transport in representative geometries (that dominate resistance)*
- *Transport in partially fractured porous media*
- *Flow around modeled subsurface instrumentation*
- *Physical models of geometries identical to those in computational particle transport models using a Lagrangian representation of the liquid*
- *Invasion percolation*
- *Flow and solute transport in fractures*
- *Effects of fracture surface roughness on flow in fractures*
- *Countercurrent flow of air and liquid in heterogeneous porous media*

Concluding Remarks

- *The large MIR system is a versatile, useful tool for examining flows in complicated situations*
- *Teaming is a normal mode of operation for INEEL*
- *The MIR system can provide valuable information for the development of _____ (fill in) _____
(and other DoE/DoD/etc. applications)*
- *The MIR system as an INEEL User Facility is valuable for collaboration with*
 - *Fluid dynamicists and convective heat transfer*
 - *other universities and industry*